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TECHNICAL NOTES FRL-TN-47

THE ANALYSIS OF ELECTRONIC TIMING CIRCUITS

PHILIP ZIRKIND

JULY 1961

FELTMAN RESEARCH LABORATORIES
PICATINNY ARSENAL
DOVER, N. J.

ORDNANCE PROJECT TS1-200

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THE ANALYSIS OF ELECTRONIC TIMING CIRCUITS

by

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July 1961

Feltman Research Laboratories
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TABLE OF CONTENTS

OBJECT

To analyze a proposed electronic counting circuit and to determine the circuit parameters compatible with fuze requirements and existing components.

ABSTRACT

General solutions were found for designing circuits for charge transfer from a charged capacitor to an uncharged capacitor via a third capacitor with varying charge.

INTRODUCTION

Antitank land mines require fuzing techniques which will:

1. Distinguish between tanks and other vehicles or personnel.

2. Initiate mine when tank is in most vulnerable position with respect to mine.

The second requirement demands that the fuze count tank bogey wheels by impact and release until the proper number have passed over it, and then fire. The circuit functions in such a way that each bogey wheel impact transfers a quantity of charge till "fire" voltage is attained. This paper describes the method of computing the charge accumulated after "n" transfers.

CONCLUSIONS

An electronic counting circuit can be utilized to initiate any voltage-sensitive device. The circuit can be pre-set to function for any number of events and to deliver any voltage compatible with the system requirement. Of the circuit parameters, the capacitor C_2 functions like a ladle to transfer the charge, and hence its capacity determines the number of counts. The other capacitor C_1 serves as a reservoir and determines the final voltage available.

ANALYSIS

Given a charge Q put on condenser C_1 at a voltage E_i, the charge distribution among the three condensers after n transfers is computed as follows:

When C_2 is first switched to C_1, both condensers will charge to the same voltage, and hence

$$\frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$

or

$$\frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$

That is, the original charge, $Q = Q_1 + Q_2$, will distribute itself proportional to the capacity. Therefore,

$$\frac{Q - Q_2}{Q_2} = \frac{C_1}{C_2}$$

or

$$\frac{Q}{Q_2} - 1 = \frac{C_1}{C_2}$$

$$\frac{Q}{Q_2} = \frac{C_1}{C_2} + 1 = \frac{C_1 + C_2}{C_2}$$

Taking reciprocals,

$$Q_2 = \frac{C_2}{C_1 + C_2} Q$$

It can be shown that

$$Q_1 = \frac{C_1}{C_1 + C_2} Q$$

Let

$$X = \frac{C_2}{C_1 + C_2}$$

Then

$$Q_2 = XQ$$

Now, when C_2 is disconnected from C_1 and connected to C_3, it, in turn, will distribute whatever charge it has between C_2 and C_3 in accordance with the aforementioned principle.

$$\frac{Q_3}{C_3} = \frac{Q_2}{C_2}$$

or

$$Q_3 = \frac{C_3}{C_2 + C_3} = \frac{C_3}{C_2 + C_3} XQ$$

Let

$$Y = \frac{C_3}{C_2 + C_3}$$

Then

$$Q_3 = XYQ$$

After one complete switch, we have

$$(1 - X)Q \text{ in } C_1,\ (1 - Y)XQ \text{ in } C_2, \text{ and } XYQ \text{ in } C_3.$$

For the second switch, when C_2 is connected to C_1, there is now charge in both condensers which must be equalized before being distributed. The total charge is

$$(1 - X)Q + (1 - Y)XQ = (1 - XY)Q$$

Now C_1 will have $(1 - X)(1 - XY)Q$ while the rest will remain in C_2, $X(1 - XY)Q$.

When C_2 is now switched to C_3, the charge in C_2 and C_3 must be added before being distributed.

$$X(1 - XY)Q + XYQ = X(1 + Y(1 - X))Q$$

Letting Z =

$$Y(1 - X)$$

then the total charge in C_2 and C_3 is

$$X(1 + Z)Q$$

yielding

$$(1 - Y)X(1 + Z)Q \text{ in } C_2$$

$$XY(1 + Z)Q \text{ in } C_3$$

Tabulating these calculations for a number of switches yields

No. of Switches	Q_1	Q_2	Q_3
1	$(1 - X)Q$	$(1 - Y)XQ$	XYQ
2	$(1 - X)(1 - XY)Q$	$(1 - Y)X(1 + Z)Q$	$XY(1 + Z)Q$
3	$(1 - X)[1 - XY(1 + Z)]Q$	$(1 - Y)X(1 + Z + Z^2)Q$	$XY(1 + Z + Z^2)Q$

No. of Switches	Q_1	Q_2	Q_3
4	$(1 - X)[(1 - XY(1 + Z + Z^2)]Q$	$(1 - Y)X(1 + Z + Z^2 + Z^3)Q$	$XY(1 + Z + Z^2 + Z^3)Q$
M	$(1 - X)(1 - XY\sum_2^\infty Z^{M-2})Q$	$(1 - Y)X\sum_1^\infty Z^{M-1})Q$	$(XY\sum_1^\infty Z^{M-1})Q$

The voltage output, E_o, will be

$$E_o = \frac{Q_3}{C_3} = (XY\sum_1^\infty Z^{M-1})\frac{Q}{C_3}$$

but

$$Q = C_1E_i$$

Therefore

$$E_o = (XY\sum_1^\infty Z^{M-1})\frac{C_1}{C_3}E_i$$

but

$$XY = \frac{C_2}{(C_1 + C_2)}\ \frac{C_3}{(C_2 + C_3)}$$

Therefore

$$XY\frac{C_1}{C_3} = \frac{C_1}{(C_1 + C_2)}\ \frac{C_2}{(C_2 + C_3)}$$

$$= (1 - X)(1 - Y)$$

$$= \frac{1 - Y}{Y}Z$$

Therefore

$$E_o = \left(\frac{1 - Y}{Y}\sum_1^\infty Z^M\right)E_i$$

From this formula, one can obtain the maximum E_o.

Since

$$\sum_{1}^{\infty} Z^M = \frac{Z}{1 - Z} \quad \text{(for 2 << 1)}$$

Therefore

$$(E_o)_{max} = \left(\frac{1 - Y}{Y} \cdot \frac{Z}{1 - Z}\right) E_i$$

Substituting for Y and Z yields

$$(E_o)_{max} = \frac{C_1}{C_1 + C_2 + C_3} E_i$$

indicating that the larger C_1 is, the closer E_o approaches E_i ultimately.

The significance of C_2 is to control the rate of transfer which will be evident from the following tables. From the general formula, one can establish the voltage transfer after each switch:

$$(E_o)_1 = \left(\frac{C_2}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right) E_i$$

$$(E_o)_2 = \left(\frac{C_2}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right) \left[1 + \left(\frac{C_3}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right)\right] E_i$$

$$(E_o)_3 = \left(\frac{C_2}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right) \left[1 + \left(\frac{C_3}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right) + \left(\frac{C_3}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right)^2\right] E_i$$

Since E_o is a function of C_1, C_2, and C_3, one can determine the significance of C_2 by tabulating the numerical influence of C_2. Since it has been established that E_o is proportional to C_1, then it will be assumed that C_1 is the largest, which reduces it to only five cases. The cases are tabulated below.

Case	Capacitor Ratio
1	$C_1 >> C_2 >> C_3$
2	$C_1 >> C_2 = C_3$
3	$C_1 >> C_2 << C_3$
4	$C_1 = C_2 >> C_3$
5	$C_1 = C_2 = C_3$

Substituting these capacitor ratios in the preceding formulas, one obtains

Case	$(E_o)_1$	$(E_o)_2$	$(E_o)_3$
1	$-E_i$	$\left(1 + \frac{C_3}{C_2}\right)\left(E_o\right)_1$	$\left[1 + \frac{C_3}{C_2} + \left(\frac{C_3}{C_2}\right)^2\right]\left(E_o\right)_1$
2	$-\frac{1}{2}E_i$	$\left(1 + \frac{1}{2}\right)\left(E_o\right)_1$	$\left[1 + \frac{1}{2} + \frac{1}{4}\right]\left(E_o\right)_1$
3	$-\frac{C_2}{C_3}E_i$	$(1 + 1)(E_o)_1$	$[1 + 1 + 1](E_o)_1$
4	$-\frac{1}{2}E_i$	$\left(1 + \frac{C_3}{2C_2}\right)\left(E_o\right)_1$	$\left[1 + \frac{C_3}{2C_2} + \left(\frac{C_3}{2C_2}\right)^2\right]\left(E_o\right)_1$
5	$\frac{1}{4}E_i$	$\left(1 + \frac{1}{4}\right)\left(E_o\right)_1$	$\left[1 + \frac{1}{4} + \frac{1}{16}\right]\left(E_o\right)_1$

Defining $\Delta(E_o)_n$ as $(E_o)_{n+1} - (E_o)_n$, one obtains $\Delta(E_o)_n = Z^n(E_o)_1$ as the general increase in voltage after the n'th switch. For each case, the result is:

Case	$(\Delta E_o)_n$ [in units of $(E_o)_1$]
1	$(C_3/C_2)^n$
2	$(1/2)^n$
3	-1
4	$(C_3/2C_2)^n$
5	$(1/4)^n$

Recapitulating these results for the first switch, one obtains:

Case	$(E_o)_1$	$\Delta(E_o)_1$
1	$-E_i$	$-\frac{C_3}{C_2}(E_o)_1$
2	$-\frac{1}{2}E_i$	$-\frac{1}{2}(E_o)_1$
3	$-\frac{C_2}{C_3}E_i$	$-(E_o)_1$
4	$-\frac{1}{2}E_i$	$-\frac{C_3}{2C_2}(E_o)_1$
5	$\frac{1}{4}E_i$	$\frac{1}{4}(E_o)_1$

As illustrations of the above cases, computations showing the actual numerical values of the second and third columns are given below and graphically illustrated in Figures 1 through 5 (pp 11 through 15).

Case 1

$$C_1:C_2:C_3::100:10:1$$

Then

$$\frac{C_2}{C_2 + C_3} = \frac{C_1}{C_1 + C_2} = \frac{10}{11};\ \frac{C_3}{C_2 + C_3} = \frac{1}{11}$$

$$(E_o)_1 = \left(\frac{C_2}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right)E_i = \frac{10}{11} \cdot \frac{10}{11} E_i = \frac{100}{121} E_i$$

$$(E_o)_2 = \left(\frac{C_2}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right)\left[1 + \left(\frac{C_3}{C_2 + C_3} \cdot \frac{C_1}{C_1 + C_2}\right)\right]E_i = \frac{100}{121}\left(1 + \frac{10}{121}\right)E_i$$

Case 2

$$C_1:C_2:C_3::10:1:1$$

Then

$$\frac{C_1}{C_1 + C_2} = \frac{10}{11};\ \frac{C_2}{C_2 + C_3} = \frac{C_3}{C_2 + C_3} = \frac{1}{2}$$

$$(E_o)_1 = E_i$$

$$(E_o)_2 = \frac{5}{11}\left(1 + \frac{5}{11}\right)E_i$$

Case 3

$$C_1 : C_2 : C_3 :: 100 : 1 : 10$$

Then

$$\frac{C_1}{C_1 + C_2} = \frac{100}{101}; \frac{C_2}{C_2 + C_3} = \frac{1}{11}; \frac{C_3}{C_2 + C_3} = \frac{10}{11}$$

$$(E_o)_1 = \frac{100}{1111} E_i$$

$$(E_o)_2 = \frac{100}{1111}\left(1 + \frac{1000}{1111}\right)E_i$$

Case 4

$$C_1 : C_2 : C_3 :: 10 : 10 : 1$$

Then

$$\frac{C_1}{C_1 + C_2} = \frac{1}{2}; \frac{C_2}{C_2 + C_3} = \frac{10}{11}; \frac{C_3}{C_2 + C_3} = \frac{1}{11}$$

$$(E_o)_1 = \frac{5}{11} E_i$$

$$(E_o)_2 = \frac{5}{11}\left(1 + \frac{1}{22}\right) E_i$$

Case 5

$$C_1 = C_2 = C_3$$

$$\frac{C_1}{C_1 + C_2} = \frac{1}{2}\ ; \quad \frac{C_2}{C_2 + C_3} = \frac{C_3}{C_2 + C_3} = \frac{1}{2}$$

$$(E_o)_1 = \frac{1}{4} E_i$$

$$(E_o)_2 = \left[\frac{1}{4}\left(1 + \frac{1}{4}\right)\right] E_i$$

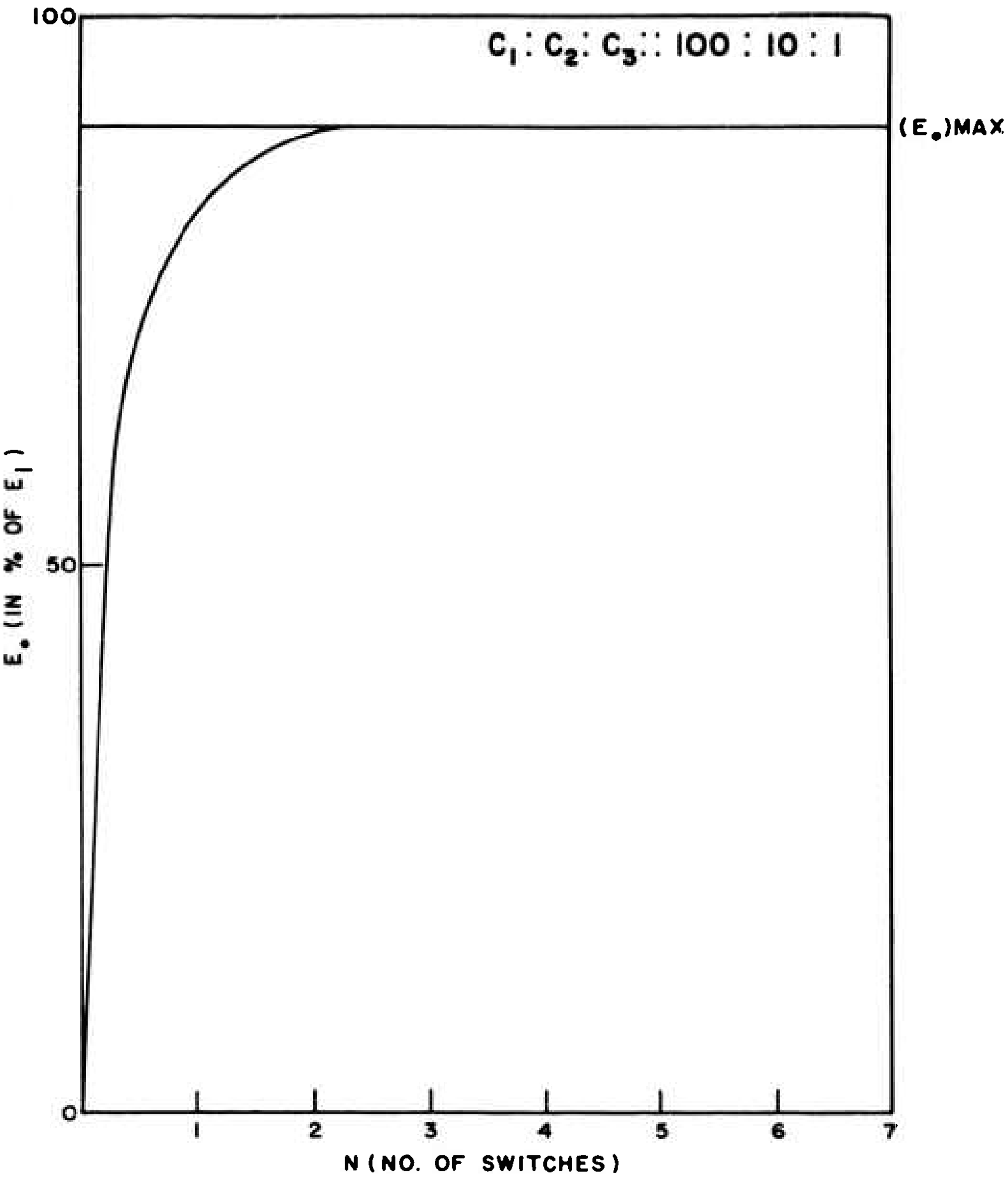

Fig 1 Case 1, where C_1:C_2:C_3::100:10:1

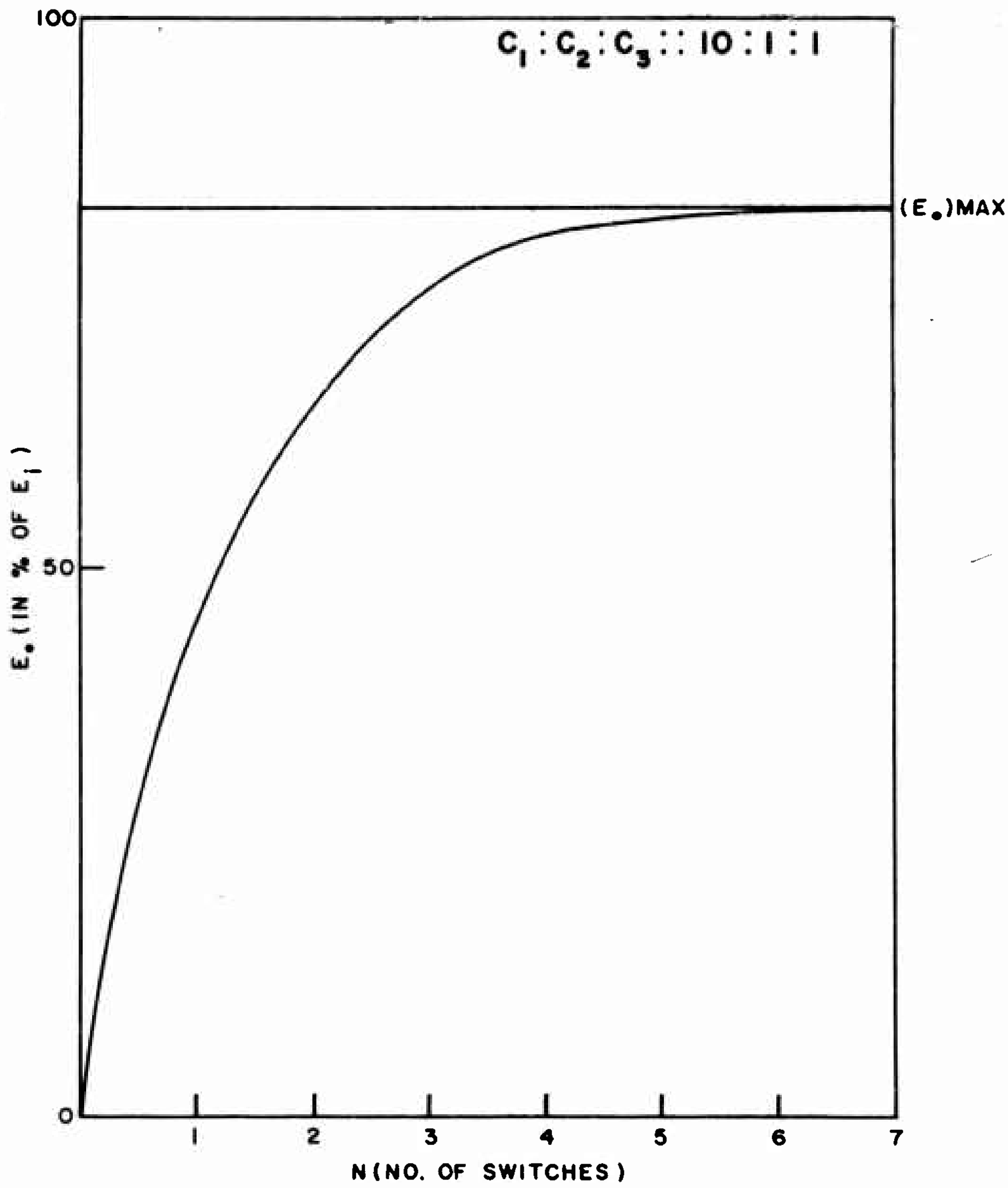

Fig 2 Case 2, where C_1:C_2:C_3::10:1:1

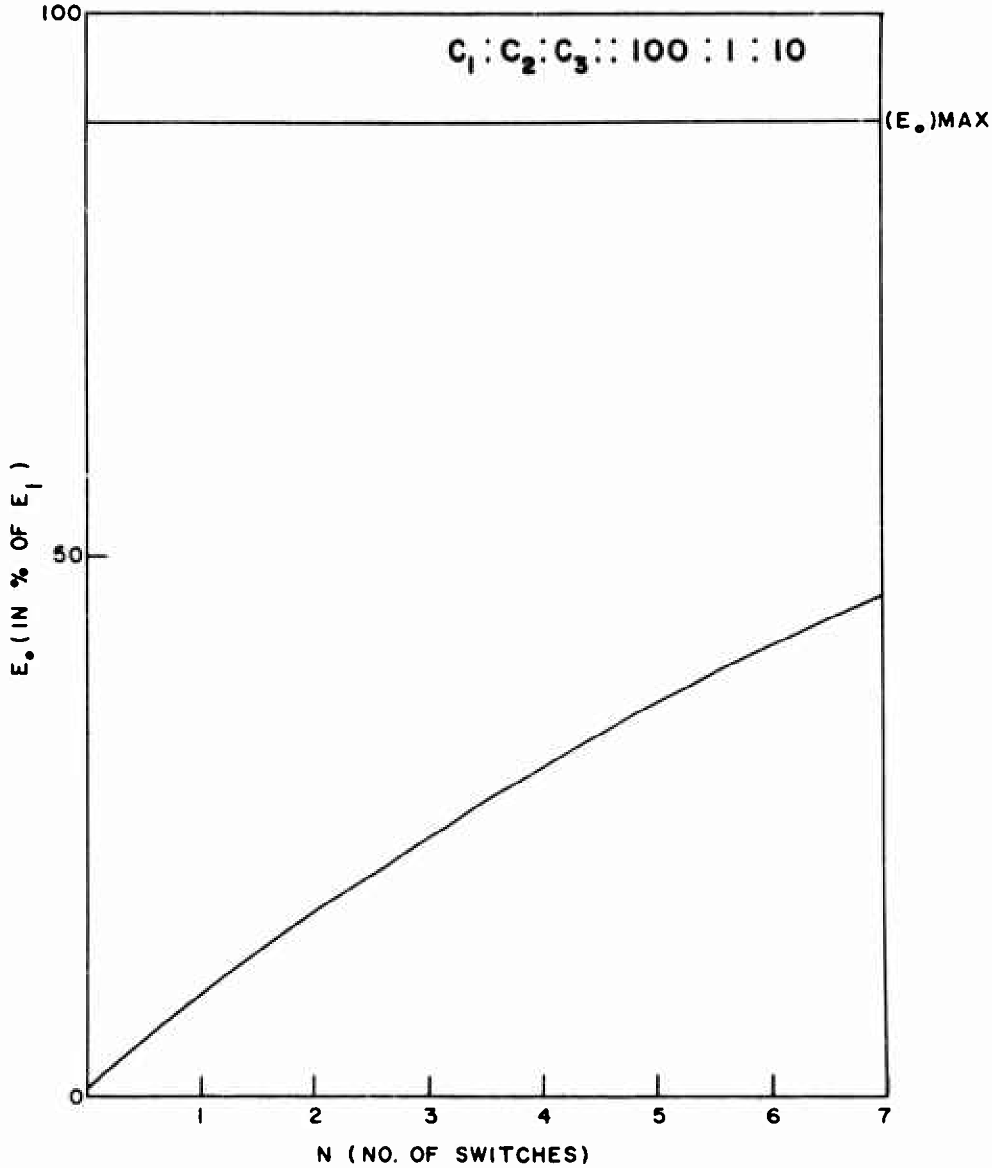

Fig 3 Case 3, where C_1:C_2:C_3::100:1:10

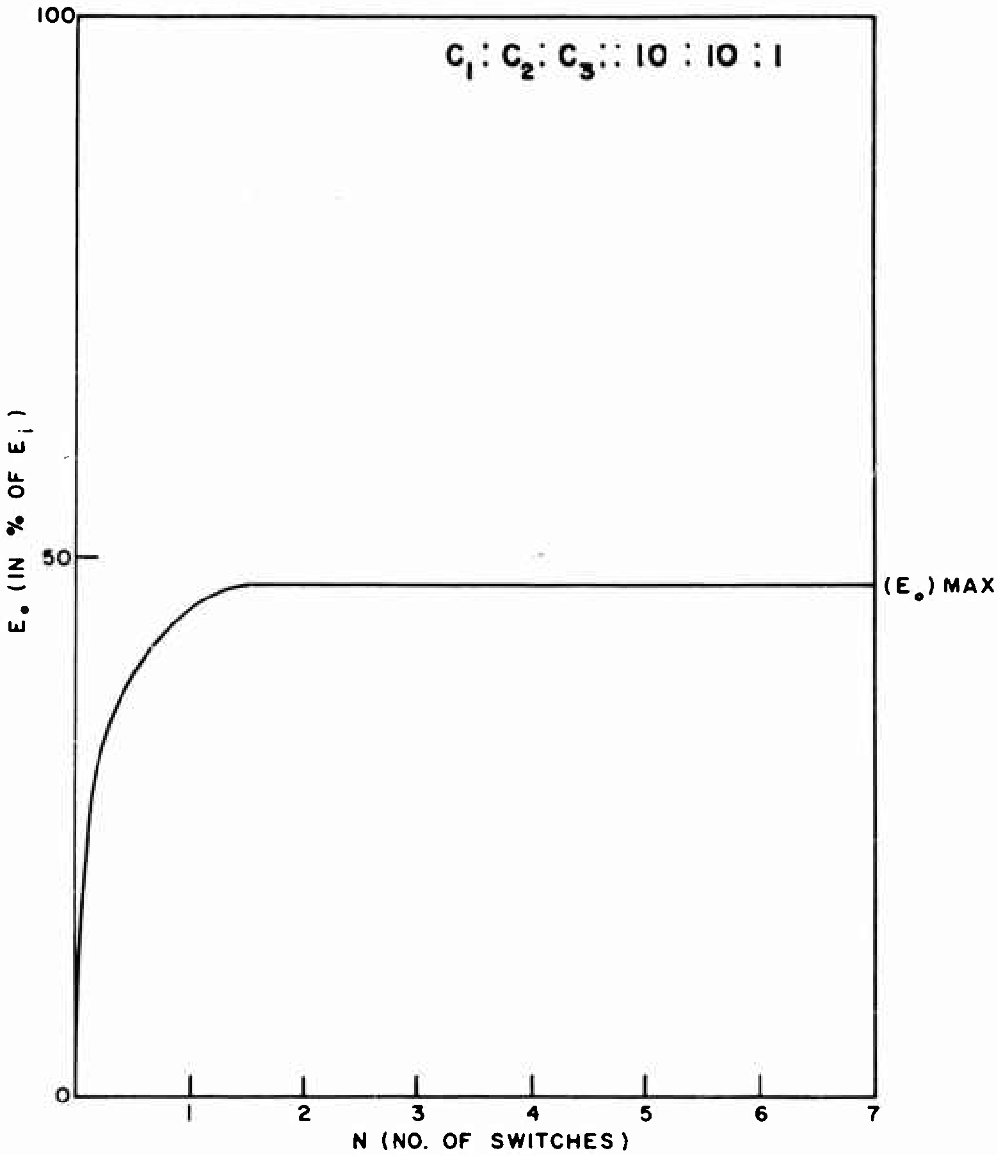

Fig 4 Case 4, where C_1:C_2:C_3::10:10:1

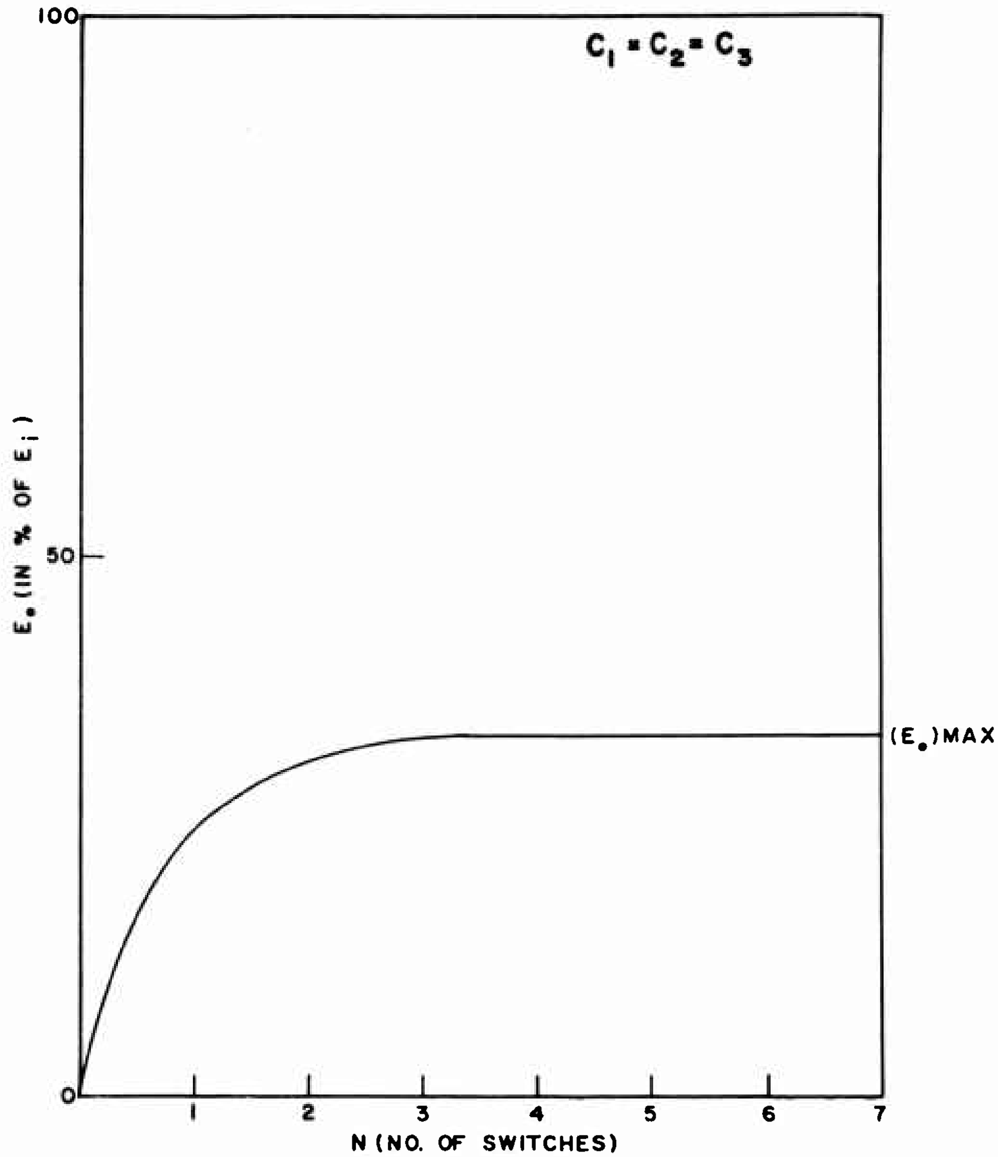

Fig 5 Case 5, where $C_1 = C_2 = C_3$

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Timing
Computers
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Analysis
Electronic
Timing
Computers
Circuit

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Timing
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Circuit

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Electronic
Timing
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Zirkind, P.
Ord proj TSI-200

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Zirkind, P.
Ord proj TSI-200

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Zirkind, P.
Ord proj TSI-200

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Antitank mine fuzes
Zirkind, P.
Ord proj TSI-200

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Analysis
Electronic
Timing
Computers
Circuit

UNCLASSIFIED

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UNITERMS

Analysis
Electronic
Timing
Computers
Circuit

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UNITERMS

Analysis
Electronic
Timing
Computers
Circuit

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Computers
Circuit

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Antitank mine fuzes
Zirkind, P.
Ord proj TSI-200

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Timing
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III. Ord proj TSI-200

UNITERMS

Analysis
Electronic
Timing
Computers
Circuit

UNCLASSIFIED

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UNITERMS

Antitank mine fuzes
Zirkind, P.
Ord proj TSI-200

UNCLASSIFIED

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UNITERMS

Antitank mine fuzes
Zirkind, P.
Ord proj TSI-200

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Antitank mine fuzes
Zirkind, P.
Ord proj TSI-200

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